

THE STATE OF THE OCEANS, PART 2

# Delving Deeper into the Sea's Bounty

The oceans, which cover 70% of the world's surface, are the least explored and least understood ecosystems on the planet. Yet today scientists realize marine organisms are becoming increasingly important as sources for new medicines and medical devices. Oceans, moreover, are sensitive indicators of climate change and environmental health.

Nevertheless, many ecosystems providing this wealth are being degraded at an alarming rate. Marine areas globally are threatened with a catastrophic confluence of pressures: overfishing, excess nutrients from sewage and agricultural runoff, toxic pollutants from giant urban centers, habitat loss, and climate change. In recent years, scientists and policy makers have been working toward a better understanding of what it will take to reclaim and protect this most remarkable source of natural wealth.

### Coral Reefs: A Critical Ecosystem

Coral reefs are among the most biologically important marine environments—and the most fragile. Located in many coastal and island areas throughout the tropical and subtropical oceans, coral reefs harbor more than 25% of all known marine fish, with some reefs reaching densities of around 1,000 species per square meter, especially in parts of the Pacific and Indian oceans. When healthy, these ecosystems are crucial assets for many coastal communities, providing food protein from thriving reef fisheries, an economic boost via tourism, and protection for beaches against erosion.

Coral reef ecosystems provide a global total of \$375 billion a year in goods and services, with about 500 million people dependent on them for food, materials, or income, according to the report *Status of Coral Reefs of the World: 2002* by the Global Coral Reef Monitoring Network, which is cosponsored by the United Nations Environment Programme and other international partners. In the Florida Keys alone, coral reefs account for \$105 million in income and more than 8,000 jobs, according to the 19 October 2001 report *Socioeconomic Study of Reefs in Southeast Florida*, produced by the National Oceanic and Atmospheric Administration (NOAA), Florida State University, and Florida consultancy Hazen and Sawyer.

But today an estimated 30% of coral reefs worldwide are “severely damaged,” and up to 60% could be lost by 2030, according to a 15 August 2003 *Science* article by marine biologist Terry P. Hughes of the Centre for Coral Reef Biodiversity at James Cook



**Sunken treasure.** Coral reefs offer abundant benefits to humans, but pollution is destroying these resources.

Left: Corbis; right: Photodisc

University in Townsville, Australia, and colleagues. Overfishing and pollution, wrote Hughes and colleagues, have been the most important causes of “massive and accelerating decreases in abundance of coral reef species.” These two factors have caused widespread changes in reef ecosystems over the past two centuries, but the past few decades have seen an exponential increase in the amount of damage done.

Of the world's 17 “megacities” with 10 million or more residents, 14 are located in coastal areas. Many of these fast-growing cities lack adequate treatment of domestic and industrial wastes. A number of them, including Jakarta, Indonesia, once had thriving coral reefs just offshore, but in recent decades excess nutrients from sewage, industrial effluent, and sediments have battered these ecosystems.

Moreover, the global seafood and aquarium trades have stripped coral reef resources. Tropical fish markets in the United States and Europe are increasingly demanding reef species. Upscale restaurants in booming Southeast Asian cities serve live fish that once inhabited coral ecosystems. It's a whole package of stressors, says John A. Musick, a marine scientist at the Virginia Institute of Marine Science in Gloucester Point, Virginia. “But it varies by region which [stressor] is most important.”

Fishers first take the largest, most valuable food fish from reefs—groupers, snappers, and sharks. Once those are gone, the fishers take large omnivores for food, then herbivores and smaller fish for the aquarium trade. This is usually followed by the decline of seagrasses and the coral itself. As the diversity of species dwindles, the health of the reef suffers.

On a healthy reef, grazing herbivores such as turtles and parrotfishes, along with other fishes, control the growth of tiny photosynthetic algae, the starting point of coral reefs' food web. When these species are overfished, small invertebrates usually take over the crucial role of controlling algal overgrowth. But instead of dozens of species that control algal growth, there might be only one or two remaining, though in huge populations.

For example, in the western Atlantic, overfishing virtually wiped out large herbivores more than a century ago. Yet super-abundant populations of the last major grazer, the sea urchin *Diadema antillarum*, held algae in check for many decades. Then, in two years during the 1980s, a mysterious disease caused a massive die-off of *Diadema*, and western Atlantic corals suffered a catastrophic collapse as a result. Once *Diadema* was gone, the algae quickly took over, forming layers of fleshy seaweed.

Coral larvae could not settle, mature, and calcify on the reefs, which started to die. The pathogen that killed *Diadema* has never been identified.

Many reef fisheries that once sustained coastal communities in developing countries have disappeared under human pressures. “In the Philippines, where overuse of marine resources is epidemic, people are

taking everything out of the reef,” says Stephen Palumbi, a marine biologist at Stanford University's Hopkins Marine Station in Pacific Grove, California, and a coauthor of the *Science* study. “You'll see scores of people diving and turning over every rock so they can make fish soup with rice. You'll see someone catch twelve fish the size of your kid's goldfish and boil



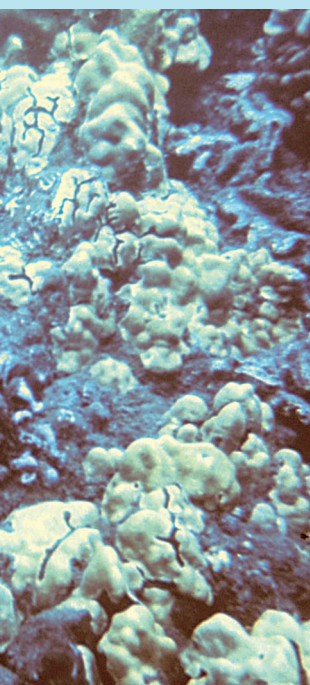
**Reefs at risk.** Species such as turtles (above) and sea urchins (below and right) keep coral ecosystems in balance by feeding on algae. The loss of such species to overfishing or pollution can be catastrophic for the reefs.



them up for soup. People are scrabbling for a tiny bit of protein, and this has serious implications for the health of those human populations."

The loss of coral reefs has also damaged their ability to perform important functions in the marine environment. "Healthy reef communities are great filters," says Palumbi, "with invertebrates

that basically spend their lives filtering the water. The biggest sponges on reefs are the best microbial filters. So we are losing the marine environment's natural purification capacity."



### Marine Pharmaceuticals

Loss of the reefs—as well as other ocean ecosystems—also means loss of untold numbers of potential medicines. The world's oceans are a huge source of still-undiscovered plant and animal species with compounds that could provide potent disease treatments. Seawater alone contains over 1 million microorganisms per drop.

By collecting species in an area with extremely high biodiversity, scientists are more likely to find biologically active compounds that could be used to make new drugs. "Everyone is looking for chemical diversity as a source for drug discovery," says William Fenical, an oceanographer with the Scripps Institution of Oceanography at the University of California, San Diego. A

poorly diverse library of molecules will not yield drugs beyond those that have already been discovered, he says, but "if you have libraries of diverse, new kinds of chemical structures, as have been found in the ocean, you're likely to find new kinds of drugs, perhaps to treat diseases with new kinds of mechanisms."

Since the mid-1980s, more than 2,500 different chemical compounds have been found in marine plants and animals. To date, only a small number of pharmaceuticals derived from marine organisms have been approved, including materials isolated from marine sponges (such as the antiviral acyclovir and the HIV/AIDS drug azidothymidine) and a pseudomarine fungus (the cephalosporin antibiotics).

Marine biotechnology, however, seems poised for a breakthrough in providing new anticancer agents. For example, *Bugula neritina*, an invertebrate that grows on ship bottoms and pier pilings, contains bryostatin 1, a powerful anticancer molecular agent that activates the immune system and inhibits cancer cell growth, says Fenical. Unlike traditional chemotherapy, bryostatin 1 does not harm healthy cells. Bryostatin 1 is in advanced clinical trials for cancer treatments. Another example is ecteinascidin 743, which has been extracted from the Caribbean sea squirt *Ecteinascidia turbinata*. In clinical trials, Fenical says, this substance is showing dramatic results in treating difficult cancers.

Fenical's research team has demonstrated that some reef dwellers can be harvested sustainably, providing income to local residents and helping to reduce overfishing. The plankton-consuming sea whip *Pseudopterogorgia elisabethae* is a soft-coral animal, purple in color and 2–3 feet in length, which lives permanently attached to coral along the entire 125-mile length of Grand Bahama Island. This creature produces anti-inflammatory agents called pseudopterins that are used as additives in skin creams.

Local harvesters, moreover, have managed this resource sustainably. In studying *P. elisabethae*, the researchers showed that when the sea whips were pruned, full regrowth of the animal would occur within 18 months. Bahamian divers start at one end of the island and over 18 months make their way along the reef, clipping and removing about two-thirds of each animal for processing and leaving the rest of the sea whip on the coral rock. "When you cut part of them off, it doesn't have any negative impact on the animal," says Fenical. "It's like pruning a tree."

This program of pruning, regrowth, and harvesting has now reached its thirteenth year. Previously, island residents overfished reef ecosystems until "there was basically



**Dual identity.** Organisms such as the Caribbean sponge (above) are the sea's microbial filters. They are also being investigated as a source for life-saving pharmaceuticals.

Clockwise from top: Photodisc; Digital Stock; James P. McVey/NOAA; Emma Hickerson/NOAA

nothing left," says Fenical. Now island residents can make \$35 a pound from sea whip harvests, compared to \$10 a pound from harvesting local lobsters.

But this project is a rarity in terms of using reef resources for something other than food or aquaria. "The single most devastating activity man is leveling at the world's ocean is overfishing," says Fenical. "We still have not been able to convince the [indigenous] people that we can invest in research and use marine resources not for food but for diverse products."

Nevertheless, the discoveries go on. "Over the past two years," says Fenical, "we are finding whole new classes of drug-producing microorganisms. . . . And we are able to culture them in our facility, using novel methods to grow these things that involve using marine-derived nutrients such as seaweed, crustacean products, and fish meal. Now we're seeing the production of a significant number of brand-new molecules that have the ability to treat human diseases. We believe that the microbiology of the world's oceans is the greatest frontier for naturally occurring medicines." Two new molecules from Fenical's facility are going into clinical trials for cancer treatment within the next six months.

Besides pharmaceuticals, coral reefs yield other medical devices, including orthopedic, cosmetic, and surgical implants derived from coral skeletons. For example, hydroxyapatite (HA), made from the exoskeletons of marine corals, fills voids caused by fractures or other trauma in bones. When HA is implanted into a bone void or hole, it allows surrounding bone and fibrous tissue to infiltrate the implant and integrate it into the body.

Reefs also yield molecular tools derived from marine organisms that use neurotoxins to protect themselves against predators. For example, research on the molecules of several potent marine neurotoxins has led scientists to greater understanding of the receptors for human pain. Scientists are studying neurotoxins to understand the membrane channels that facilitate the transmission of nerve signals. As these scientists learn more about how neurotoxins function to attack nerve transmission, they can design drugs to target those same sites of transmission, helping to reduce pain. Biotechnology research firms study and develop these probes for sale to pharmaceutical firms that seek to create new drugs.

### Oceans and Climate Change

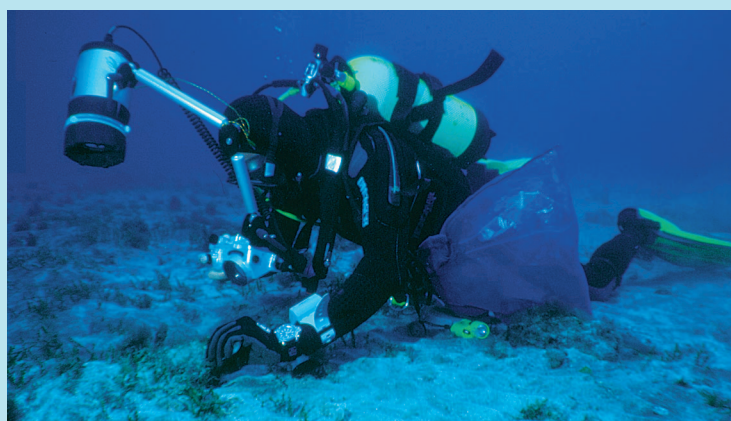
The oceans—and mankind's effects upon them—are a major driver of changing climate patterns that cause intense weather such as floods and droughts around the world. At the heart of these changing patterns is a phenomenon called the El Niño–Southern Oscillation (ENSO), a complicated interplay between ocean and atmosphere in the Pacific Ocean.

El Niño is not new; indeed, climate proxy records including sediment cores and coral studies show that it has occurred for thousands of years. Every 2–7 years, along the coasts of Peru and Ecuador, warm water appears usually around Christmas; thus El Niño ("little boy" in Spanish) refers to the Infant Jesus. The NOAA Climate Prediction Center announced in September 2003 that academic and government scientists had reached a consensus about definitions for ENSO events. An El Niño event is

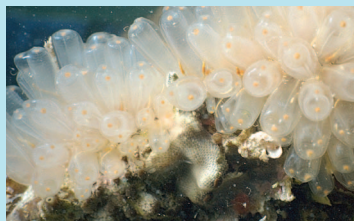
characterized by a three-month warming of 0.5°C above normal (for the 1971–2000 base period) in a tropical area from the west coast of South America to the central Pacific Ocean. The opposite phenomenon, La Niña ("little girl"), is characterized by a three-month cooling of 0.5°C over the same period in the same region. "Southern Oscillation" refers to fluctuations in air pressure that accompany El Niño and La Niña.

During El Niño, trade winds in the central and eastern tropical Pacific die down, and ocean temperatures become unusually warm there. Increased amounts of heat and moisture then rise from the sea surface into the atmosphere, driving heavy rains and flooding across the western coast of South America. This atmospheric change disrupts high-altitude wind currents, which in turn alter distant weather systems across the tropics and portions of the mid-latitudes. During El Niño years, for example, drought usually comes to Southeast Asia, Indonesia, and southern Africa, while flooding comes to the southwestern United States, Argentina, Kenya, and many other nations and regions.

The other half of the ENSO cycle is La Niña. During a La Niña event, which usually follows El Niño, the central and eastern tropical Pacific is cooler than usual, but the western Pacific is much warmer. La Niña causes opposite effects from El Niño. Where El Niño spawns floods in a particular region, La Niña can cause droughts. The La Niña event spanning 1998–2002 is blamed for droughts and record high temperatures spanning the United States, the Mediterranean, southern Europe, and Southwest and Central Asia, wrote Martin Hoerling of the NOAA Climate Diagnostics Center and



**Delving for new drugs.** Researchers from PharaMar collect specimens from the sea floor (above) and isolate compounds that may be used in drugs. An anticancer drug was developed from the Caribbean sea squirt *Ecteinascidia turbinata* (right).



PharaMar

Arun Kumar of the NOAA Climate Prediction Center in a 31 January 2003 *Science* article.

Global climate change has apparently affected ENSO's intensity and impacts. Global warming of 0.6°C over the past century was caused by increased greenhouse gases produced largely from human activities such as the burning of fossil fuels in coal-fired power plants, automobiles, and other sources, according to the Intergovernmental Panel on Climate Change (IPCC) report *Climate Change 2001*.

The tropical ocean, however, has warmed even more than the rest of the Earth's surface over the past 50 years; again, this is due partly to human actions. Hoerling and Kumar report that the warming of 1°C since 1950 of the tropical Indian Ocean and the west Pacific Ocean is "beyond what could be expected of natural variability and is partly due to the ocean's response to increased greenhouse gases."

Increased greenhouse gases are trapping more infrared energy in the atmosphere, and much of that energy entrapment must

logically find powerful expression in the tropical ocean, says James White, a climate scientist at the University of Colorado. Climate change over the next several decades will indeed increase climate extremes and climate variability, according to IPCC projections. The El Niño cycle is the Earth's strongest driver of climate variability, next to the seasons. Therefore, researchers have been studying ENSO and its impacts to learn what future climate change could mean for public health, according to Jonathan Patz, a physician and director of the Program on Health Effects of Global Environmental Change at the Johns Hopkins Bloomberg School of Public Health.

The Tropical Ocean–Global Atmosphere observing system in the Pacific Ocean provides enhanced El Niño forecasting, which has economic benefits for farmers and other resource-based enterprises. For example, researchers led by Andrew R. Solow, director of the Marine Policy Center at the Woods Hole Oceanographic Institution, estimate the economic benefits of El Niño forecasts for U.S. agriculture at \$323 million a year in

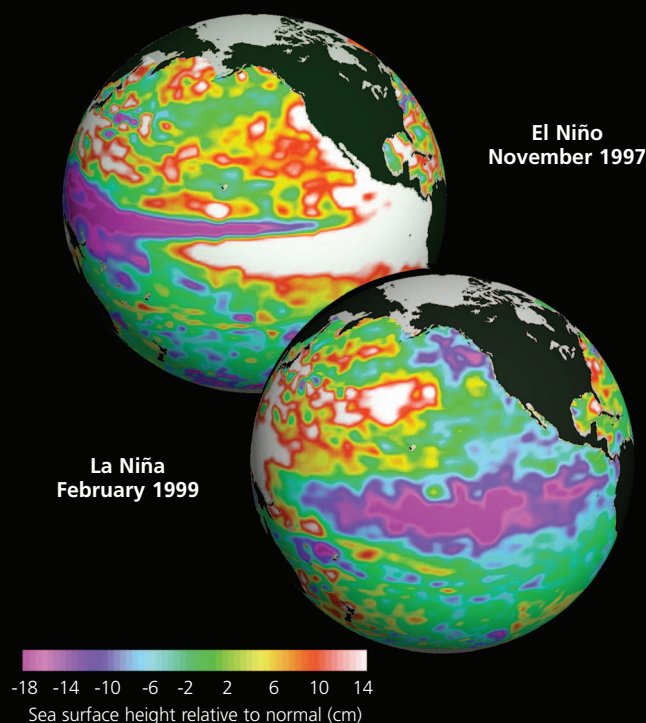
a report in the May 1998 issue of *Climatic Change*. When added up across all economic sectors, the estimated value of improved El Niño forecasts reaches \$1 billion a year, according to a September 2002 NOAA report, *Linking Economic and Environmental Goals in NOAA's Strategic Planning*.

## ENSO and Disease

Many recent studies have focused on fluctuations in diseases that might be caused by short-term climate oscillations such as El Niño. Researchers have studied disease-carrying organisms—especially mosquitoes—that alter their range when regional climate changes. Some studies have examined whether disease carriers move into new areas and reach fresh victims whenever El Niño brings heavy rains.

But it has been hard to pin down the connections between El Niño and disease outbreaks because health databases are scarce or inconsistent in quality, Patz noted in a commentary in the 1 October 2002 issue of *Proceedings of the National Academy of Sciences*. Studies have been limited by many

## Sea Surface Height during El Niño and La Niña



**Water and weather.** The climate phenomena El Niño and La Niña result from a complicated interplay between the atmosphere and the ocean, and can result in extreme floods and droughts (the Russian River flood at the top right resulted from the El Niño event depicted at left). Determining how these events are affected by climate change may help in predicting the disasters that can accompany them.

confounding factors, he wrote, including increased trade, migration, travel, human population growth, urban sprawl, emerging drug and pesticide resistance, and erratic disease control efforts, among others.

By the 1960s, scientists were noticing that cases of cholera in Bangladesh would spike in warm weather when coastal algae bloomed. But researchers didn't know whether this was a coincidence. Then in the early 1980s, Rita Colwell, now chair of the newly created Canon U.S. Life Sciences, and colleagues in Bangladesh discovered that the El Tor strain of *Vibrio cholerae* could reduce in size 150–300 times to tolerate cold or changes in the ocean's salinity. So in colder weather, the bacterium would go into hiding beneath the mucous outer coating of algae, becoming so small that collection filters could not pick it up. But when coastal surface waters were fertilized by the nutrients in raw sewage and warmed by El Niño, algal blooms would grow there, as would the cholera bacterium in both size and abundance. At low concentrations, *Vibrio* will not infect people, but at higher abundance, the bacterium disrupts water intake in the human body, resulting in extreme dehydration.

A recent study has succeeded in “finding a robust relationship between El Niño events and cholera prevalence in Bangladesh, spanning a 70-year period,” wrote Patz in his 2002 commentary. In that study, published in the 1 October 2002 issue of *Proceedings of the National Academy of Sciences*, Xavier Rodó, a physical scientist at the University of Barcelona, and colleagues found that ENSO events caused more than 70% of the variance in cholera mortality and morbidity, and that ENSO had increased in frequency and intensity since the late 1970s.

It also seems clear that ENSO events have severely damaged coral reefs, which are highly sensitive to rapid changes in temperature. During some ENSO events, overheated corals expel most of their symbiotic algae that provide the necessary nutrients for reef building. As a result, the coral cannot calcify and rebuild its foundation. When these algae are gone, corals become pale or white. If this heat stress is intense or continues for a long period, many corals die. During the 1982 El Niño, there were massive coral die-offs in the central and eastern Pacific, the Persian Gulf, and the tropical western Atlantic. The reefs had barely begun to recover when El Niño returned in 1991–1995, battering these systems again.

### Harnessing the Oceans' Energy

In Europe and the United States, researchers and commercial investors have made strides toward creating new technologies to harness

the ocean for renewable energy. There are four practical methods of realizing energy from the seas, although they raise various questions of economic feasibility and potential for damage to ocean ecosystems.

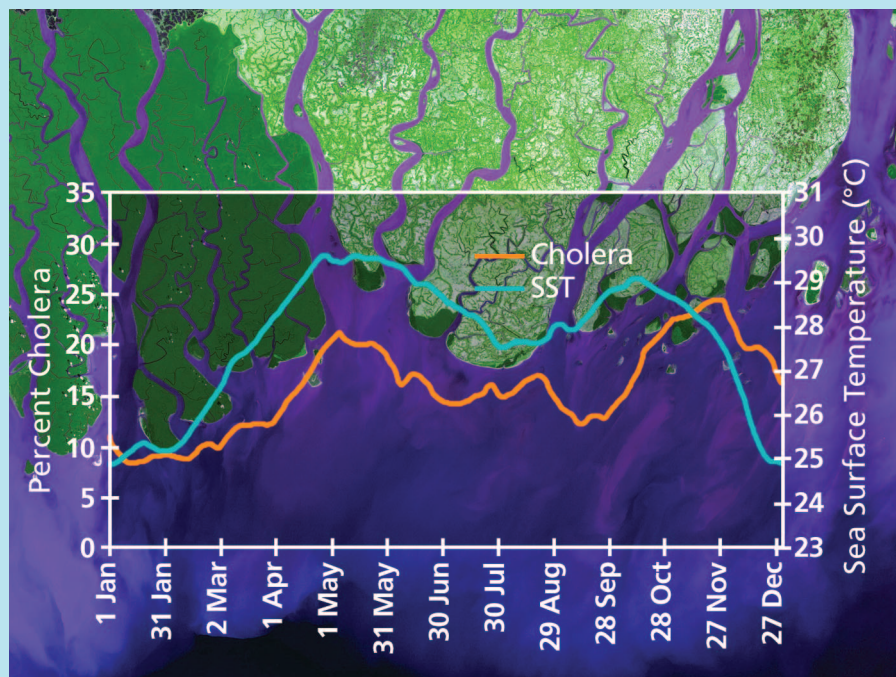
The first is tidal power, which takes advantage of the gravitational pull of the moon, harnessing energy from the difference between high and low tides of 16 feet or more. A dam across an estuary forces water through turbines that turn a generator. The largest tidal power project in the world is a 240-megawatt plant near Saint-Malo, France. There are no planned or existing tidal power projects in the United States; in the United States only Alaska and Maine experience the large tidal differences that are necessary to make such plants feasible. [For more information about tidal power, see “Tidal Turbines: Wave of the Future?” *EHP* 112:A26 (2004)].

The second form is wave energy. Wave energy technologies for offshore use include floating or pitching devices placed on the surface of the water that convert the horizontal or vertical movement of the waves into mechanical energy that is used to drive a turbine. European nations—especially Denmark, the United Kingdom, and Germany—are the world leaders in research and development of wave energy technology; growing numbers of offshore projects are being licensed in these countries. For the United States, the West Coast has the highest wave potential. One U.S. project moving

forward is an installation of electricity-producing wave energy buoys more than 3 nautical miles offshore of Washington State, in the Olympic Coast National Marine Sanctuary. According to the *Renewable Resources Development Report*, a November 2003 study by the California Energy Commission, wave energy currently is most economically practical in niche markets such as those near the end of a distribution grid or in isolated areas not connected to the grid.

The third kind of ocean energy, ocean thermal energy conversion, is limited to tropical regions such as Hawaii and the southernmost reaches of the U.S. Atlantic coast. The surface waters of the world's tropical oceans store huge quantities of solar energy, but there are no commercial technologies to capture this energy. Ocean thermal energy conversion uses the temperature difference between the ocean's warmer top layer and the colder deep water to generate electricity, among other applications. Facilities require that a large intake pipe be submerged offshore to draw colder water up to the surface, and this kind of infrastructure is expensive.

According to the *Renewable Resources Development Report*, these three ocean energy technologies currently are too expensive to compete with traditional power sources. All of these technologies would be difficult to push through permitting processes, as well. The report notes issues such as “disturbance or destruction of marine life, possible threat



**A meaningful monitor.** A recent study has shown a strong correlation between El Niño events (which may affect concentrations of the *Vibrio cholerae* bacterium) and cholera prevalence in Bangladesh.

to navigation from collisions, and degradation of scenic views from energy devices and transmission lines located near or on the shore.” However, the fourth kind of ocean energy, offshore wind power, is seeing promising developments in the United States and abroad.

The first proposal for offshore wind energy development in the United States calls for the use of about 23 square miles of Nantucket Sound, 5.5 nautical miles off the coast of Cape Cod, Massachusetts, in Horseshoe Shoal. The Cape Wind project, developed by the Boston-based Cape Wind Associates, would include 170 wind turbines sunk into the ocean floor and rising 420 feet above the ocean surface, generating an annual average of about 160 megawatts of electrical power. According to a U.S. Army Corps of Engineers New England District fact sheet of 8 March 2004, opponents of the project are concerned about the precedent of private gain in public waters without compensation, and the potential for damage to birds, marine mammals, and tourism and fishing economies.

Europe is where wind energy projects have advanced the farthest. The first European projects were small in scale and located in nearshore areas where it is shallow or sheltered. Now there are 10 wind energy projects operating in open-ocean areas, where winds are much stronger, in Denmark, the Netherlands, Sweden, and the United Kingdom, according to the British

Wind Energy Association, a trade organization. The largest project to date opened at Horns Rev in Denmark in 2002, generating an annual average of 160 megawatts.

### Carbon Containment

Until ocean energy technologies are developed further, industrialized nations will continue to fossil fuels to create energy for factories, domestic use, and vehicles. Might the oceans serve another purpose in the meantime? Recent concerns over climate change and the role of greenhouse gases in increasing the greenhouse effect have heightened interest in sequestering more carbon in the oceans. Oceans already absorb, release, and store huge amounts of carbon dioxide ( $\text{CO}_2$ ) from the atmosphere. There are two potential methods of enhancing the ocean's capacity to sequester carbon, both of which take advantage of the ocean's natural processes, although no pilot or commercial applications of these methods have yet been conducted.

The first approach is to enhance the productivity of ocean biological systems through fertilization. The ocean surface already absorbs millions of tons of  $\text{CO}_2$  from the atmosphere every day. Experimental results show that increasing the concentration of iron and micronutrients in certain ocean waters can greatly increase the growth of phytoplankton at the ocean surface, and phytoplankton would absorb more  $\text{CO}_2$ . Researchers hypothesize that the phytoplankton would drive a “biological pump”

that would draw organic material—and the  $\text{CO}_2$  in the surface waters—into deeper waters, where it could be stored.

The second approach is to sequester  $\text{CO}_2$  in the deep ocean using semiliquid compounds called hydrates. On the ocean floor, intense pressures cause  $\text{CO}_2$  to combine with seawater to form hydrates. In a study published 7 May 1999 in *Science*, Peter G. Brewer, an ocean chemist with California's Monterey Bay Aquarium Research Institute, led a research team that injected liquid  $\text{CO}_2$  into seawater off the California coast at a depth of 3,627 meters. The  $\text{CO}_2$  quickly reacted with the seawater and formed hydrate that swelled in volume to many times its original size and formed a “skin” that enclosed the  $\text{CO}_2$  like a bubble. The researchers acknowledge that permanent disposal of  $\text{CO}_2$  as hydrate on the sea floor probably is not realistic, although quite long residence times may very well be possible.

### Making Water from Water

On a planet that's two-thirds water, it's a bit of irony that scarcity of potable water is such a grave problem. For centuries, humans have looked for ways to remove the salt and other minerals from seawater or brackish water to produce drinking water. Today, there are 11,000 desalination facilities operating in 120 countries around the world, producing about 4 billion gallons of drinking water daily.

Most desalination plants use traditional distillation, which involves heating seawater



**Ocean windfall.** At Horns Rev in Denmark, ocean winds are harnessed for energy. The largest such project to date, it generates an annual average of 160 megawatts.

to produce steam. The steam condenses back into water, though with greatly reduced salt concentrations. The most significant disadvantage of distillation is that it is highly energy-intensive. So it is usually used in places where energy costs are low, such as the Middle East.

The other desalination technique is reverse osmosis, which involves pumping seawater or brackish groundwater through semi-permeable membranes to separate salt and other minerals from the water. The energy costs of this technology are much lower than for distillation, and the amount of potable water derived from the "feed water" is usually higher. Costs of reverse osmosis have fallen significantly in recent years. Desalinating an acre-foot of seawater cost \$2,000 in 1990, but this has been cut to \$900 today, according to the U.S. Desalination Coalition. This Washington, D.C.-based organization comprises 13 water agencies and utilities from California to Florida and is seeking an increased federal role in advancing desalination.

There are disadvantages to reverse osmosis, however. The membranes tend to clog, and they require cleaning, according to a March 2004 report by the California Coastal Commission, *Seawater Desalination and the California Coastal Act*. The feed water also must be extensively pretreated, often by using biocides, coagulants, and other compounds. The process of reverse osmosis and its use of cleaning agents generates wastes that can include toxic chemicals, metals, and other materials that are discharged back into the sea. Desalination plants also release a highly concentrated salt substance called brine that can affect marine life when it's discharged back into the ocean.

California already has about a dozen existing desalination facilities along its coastline, though they are relatively small. In total, they produce about 3,300 acre-feet per year. About two dozen more desalination facilities are proposed, and some would be the largest in the country. The total output of all proposed facilities would produce about 260,000 acre-feet per year, an 80-fold increase over current production.

### Preparing for the Future

Three years ago, the U.S. Commission on Ocean Policy—a mix of 16 academics, business executives, and naval officers—was appointed by President Bush to make recommendations on how to improve the capacity of the nation to manage ocean- and coast-related activities. On 20 April 2004, the commission released a 500-page preliminary report to state governors and the public for comment. The comment period on the preliminary report ended 21 May 2004, where-

upon the commission began reviewing comments received from the governors and the public. Once all comments are considered, the commission will deliver its final report and recommendations to President Bush and Congress. When completed, the report will be the most comprehensive national assessment of U.S. oceans in 35 years.

In the preliminary report, the commission offered nearly 200 recommendations to President Bush, Congress, and various federal agencies, and urged that the federal government double the budget for ocean research (which is now \$650 million annually) over the next five years. The report also calls for an eventual \$246 million annual investment in ocean education. The report points out the need for creating measurable water pollution reduction goals, especially for nonpoint source pollution, and for significantly reducing nonpoint source pollution in all impaired coastal watersheds.

Other actions recommended by the commission include the establishment of a National Ocean Council, chaired by an assistant to the U.S. president, to oversee ocean policy and 20 federal ocean-related agencies, and the creation of a new governance structure, based on ecosystem-based management, for the conservation of oceans. Ecosystem-based management recognizes all components of an ecosystem—physical, biological, chemical, and human—and the linkages among them. Fisheries management must be reformed by requiring regional fishery management councils to rely on scientific advice

to determine how many fish can be caught without further depleting stocks.

The commission also called for more attention to ocean education through coordinated formal and informal programs, and the generation of more and better scientific information about the oceans. Volunteer regional ocean councils should be established to address regional issues, and an Ocean Policy Trust Fund should be created based on revenue from offshore oil and gas development and "other offshore uses" (which could include fish farming, deep-sea mining, and bioprospecting for new drugs) to pay for the eventual \$3 billion annual cost of implementing the recommendations. The trust fund would be modeled after the Highway Trust Fund for transportation projects.

The commission also strongly urges the creation of a comprehensive national network of ocean observatories that would help better track marine resources and climate. "There is a desire," says commissioner Marc J. Hershman, an ocean policy professor at the University of Washington, "to advance the idea of observing and understanding the ocean in the same way we observe the atmosphere and provide real-time information about climate."

The problem now is that observations of U.S. marine ecosystems are scattered among more than 40 different systems that use various protocols, according to the commission report. Moreover, federal agencies do not usually share observation data with state resource managers or with academic programs. There



**Water for a thirsty world.** "Desalination Pipes," a sculpture by Mustafa Senbel, stands in front of a multimillion-gallon desalination plant in Jeddah, Saudi Arabia. As global potable water resources dwindle, desalination becomes an even more vital technology.

Robert Reis/Alamy

are many different kinds of observation systems, including satellite remote sensing, ship-based observation, and autonomous offshore monitoring efforts.

However, one effort, the nonprofit Gulf of Maine Ocean Observation System (GoMOOS), could provide a working prototype for a planned national observation system. GoMOOS was established in 2001 to integrate observation programs and protocols in the region stretching from Cape Cod to Nova Scotia. GoMOOS, based in Portland, gathers data from moored buoys, platforms, drifters, and onshore radar systems. These devices record and report wind speed, wave activity, visibility, air temperature at various depths, water salinity, and more. Computer models translate the data and identify currents and predicted conditions of wind, waves, and currents.

The information is placed online at <http://www.gomoos.org/> and is available to the public. Now anyone can tap into usable databases of meteorologic and oceanographic information gathered 24 hours a day from the Gulf of Maine. This information can help improve shipping, better prepare for hurricanes and their aftermath, reduce some public health and safety risks, and protect and restore healthy marine systems. Users include shipping companies, recreational boaters, search-and-rescue personnel, research scientists, and public health officials.

Fishery managers say they need better data about currents and other ocean processes so they can provide more accurate stock

assessments. "GoMOOS provides the environmental background information that helps fishery managers do stock assessments," says Philip Bogden, chief executive officer of GoMOOS. From observation systems such as GoMOOS, fishery managers could gain better information about the dynamics of nearshore and estuarine mixing. This would be important in understanding how some fishery populations move from nursery grounds nearshore to adult habitat offshore, says Hershman.

Hershman further says, "Observing systems could more carefully track ocean mixing processes that are indicators of the kind of food sources that would come in and out of the estuaries." Resource managers could also track pollutants that are transported in the coastal ocean. Ocean mixing, tides, and temperatures also strongly affect the distribution and proliferation of some kinds of harmful algal blooms, among other disease threats.

More research appears to be forthcoming shortly. In November 2002, the NIEHS and the National Science Foundation invited applications for research programs to explore the relationship between marine processes and human health. This joint initiative commits \$6 million annually to establish "centers of excellence" focusing on harmful algal blooms, water- and vectorborne diseases, and marine pharmaceuticals. The four new centers funded under the initiative were announced in April 2004 [see "New Centers for Oceans and Human Health," p. A468 this issue].

In March 2004, the U.S. Senate passed the Oceans and Human Health Act (S.1218), sponsored by Senator Ernest F. Hollings (D-SC). The Oceans and Human Health Act supports research on the interaction between human health and the marine environment, and contains a provision that would authorize \$80 million for a new NOAA oceans and human health initiative. A committee would comprise representatives from NOAA, the National Science Foundation, the NIEHS, the Centers for Disease Control and Prevention, the U.S. Environmental Protection Agency, and the Department of Defense. The committee would be expected to develop a 10-year plan detailing the research program's execution.

It is clear that interactions between the oceans and the atmosphere affect regional climate conditions around the world. Oceans have also become increasingly important as sources for new medicines, energy, drinking water, and many other uses. Traditional uses of the ocean such as fishing are still crucial to many coastal communities. But fractured management schemes, overfishing, and rapid development are destroying many of the ecosystems that support these uses. Policy makers and the public should understand that the oceans must be protected as a remarkable resource of natural wealth.

**John Tibbetts**

*Editor's note:* "The State of the Oceans, Part 1: Eating Away at a Global Food Source" appears in our April 2004 issue [EHP 112:A282–A291 (2004)].



**Global asset.** The oceans, which sustain much of life on this planet, will continue to do so only if their bounty is harvested in sustainable ways.